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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 752

HUMAN FACTORS EVALUATION OF SUBMARINE ESCAPE

IV: Evaluation of Submarine Escape and Survival Equipment Mark 1 Mod 0 for Side and Top Egress with Two Disconnect Systems

by

Bernard L. Ryack, Ph.D.
and
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Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4306.03-1020DXC5.02

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Naval Submarine Medical Research Laboratory

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SUMMARY PAGE

THE PROBLEM

To evaluate a new submarine escape appliance, Escape and Survival Equipment, Mark 1, Mod 0 (EASE) and two systems for rapid separation of the appliance from the escape trunk air supply, automatic friction disconnect and manual disconnect.

FINDINGS

Egress with the EASE compares favorably to that with other escape appliances. Under non-stressful conditions speed of separation is equivalent for the two disconnect configurations.

APPLICATION

The research described in this report should contribute to the development of an improved submarine escape system incorporating exposure protection and other desirable features of the EASE.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit M4306.03-1020DXC5 - Development of Diver Performance Measurement Methods. The manuscript was submitted for review on 13 June 1973, approved for publication on 12 September 1973 and designated as NavSubMedRschLab Report No. 752.

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ABSTRACT

A newly developed submarine escape appliance, Escape and Survival Equipment, Mark 1, Mod 0 (EASE), which provides exposure protection for the escapee was evaluated for side egress and top egress escape trunk configurations. Two systems for rapid separation of the escape appliance from the escape trunk air supply, automatic disconnect and manual disconnect, were also evaluated. Escape capability with the EASE was found to be comparable to that with other escape appliances. Although the automatic disconnect was more rapid than the manual disconnect, the difference was not significant. However, the magnitude of this difference might be expected to increase under the stressful conditions of an actual escape. As reported in previous studies, top egress was superior to side egress. Adoption of the EASE for use in submarine escape systems is recommended.

HUMAN FACTORS EVALUATION OF SUBMARINE ESCAPE

IV: Evaluation of Submarine Escape and Survival Equipment Mark 1 Mod 0 for Side and Top Egress with Two Disconnect Systems

INTRODUCTION

In previous studies Ryack, Rodensky, and Walters[1], Ryack and Walters[2], and Ryack, Walters, and Rodensky[3] investigated escape capability from the three escape trunk configurations found in United States Navy Submarines, side egress, tube egress, and top egress (Figure 1), for one-man, two-man, and three-man teams. Two escape appliances which facilitate ascent to the surface were utilized in these studies, the Steinke Hood, currently in use by the United States Navy, and the Mark VII Submarine Escape Immersion Suit, (SEIS) developed by the British Royal Navy. The SEIS consists of a buoyancy stole and hood, which are inflated with air prior to escape, and an exposure protection component which is inflated with CO_2 when the escapee reaches the surface. The Steinke Hood is composed of a stole and hood, similar to that of the SEIS, but has no exposure protection component. Figure 2 illustrates the differences between the two appliances. A more detailed comparison is made in Ryack, Rodensky, and Walters[1] and in Ryack and Walters[2]. In their evaluations of escape capability with the two appliances, these authors found that for a given team size and trunk configuration there were only minor differences in escape time between them.

The SEIS has the advantage of providing exposure protection while the escapee is on the surface. However, several difficulties are encountered in utilizing the SEIS with existing United States Navy escape trunk configurations and hardware. The appliance requires a special Hood Inflation System (HIS) and an independent air supply.[4] The necessity of installing these on existing submarines might make adoption of the SEIS impractical. The SEIS was designed to be used with a top egress trunk configuration and the lower portion of the hood was left open for venting as the escapee ascends to the surface. While this system works well for top egress, there is danger of loss of the breathing-air-bubble while the escapee is positioning himself for a side or tube egress. Loss of this bubble does not provide a major difficulty for the experienced diver but could result in panic and drowning with a non-experienced escapee.

To overcome the difficulties inherent in the use of the SEIS a modified version of the appliance, Escape and Sur-

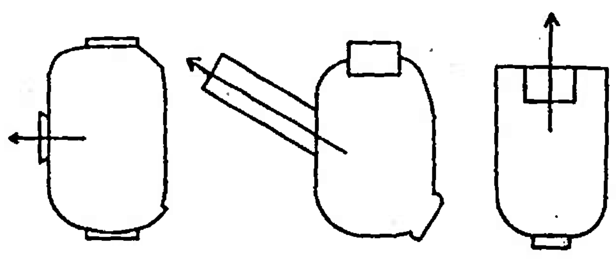

Fig. 1. Schematic representation of the side, tube and top egress escape trunk configurations found in United States Navy Submarines. Arrows indicate direction of escape.

Fig. 2. Subjects wearing the British Mark VII Submarine Escape Immersion Suit (left) and the Steinke Hood (right). The exposure component of the suit is inflated.

vival Equipment, Mark 1, Mod. 0 (EASE), was developed.[5] The major similarities and differences between the two appliances are shown in Figure 3. On the EASE the hood is completely closed and venting is provided by two relief valves, the conventional Schrader fitting (requiring manual disconnect from the inflation system) replaces the stole inflation tube (an automatic friction disconnect connection between the SEIS and the HIS), and a snorkel eliminates the need for an independent air supply (the escapee breaths air in the trunk prior to escape). Additionally, the SEIS is fabricated from rubberized cotton and the EASE from polychloroprene-coated-nylon.

It was anticipated that the differences between the two escape appliances would not result in any difference in escape capability. The primary purpose of this study was to evaluate this hypothesis.

As previously indicated, part of the HIS consists of an automatic friction disconnect between the SEIS and the escape trunk hardware;[4] the Steinke Hood utilizes a Schrader connector requiring a manual disconnect by the escapee.[6] To provide for both types of connections, Ryack, Walters, and Rodensky [3] used a specially designed connector (Type I) which permitted utilization of both the SEIS and the Steinke Hood with no hardware change over. The essential features of the Type I connector and of the standard Schrader connector are illustrated in Figure 4. The Schrader connector (Figure 4-II) consists of

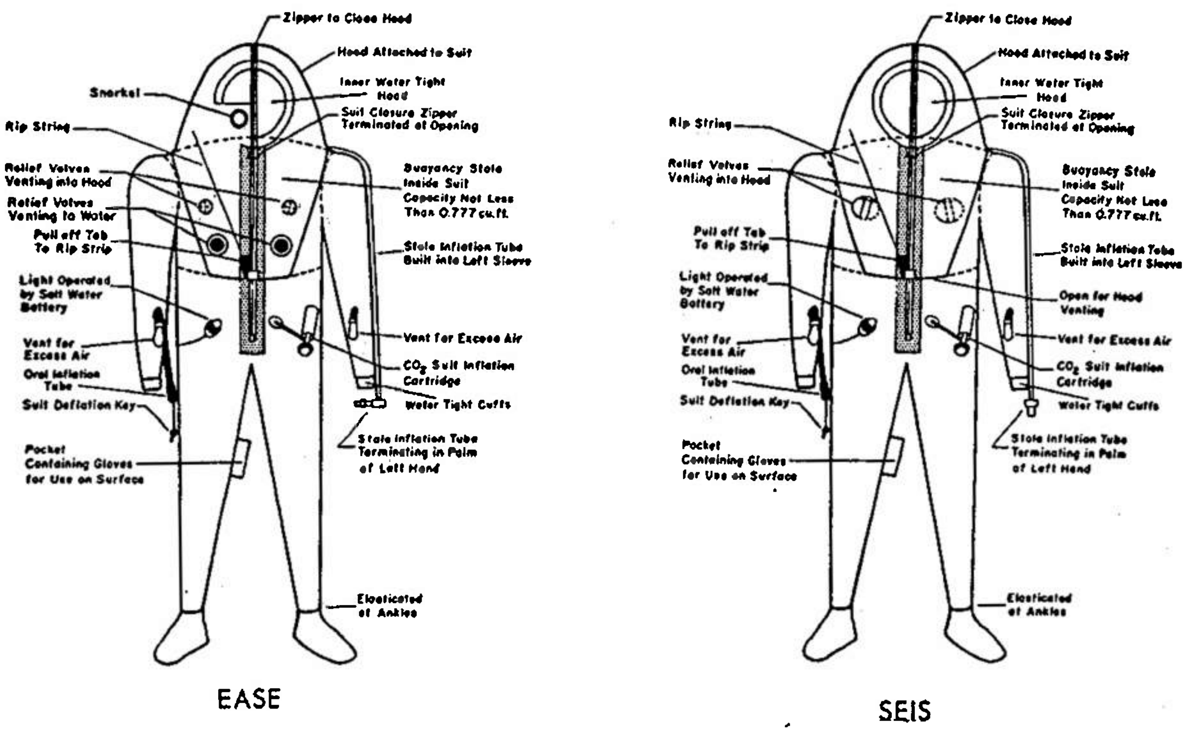

Fig. 3. Details of the Escape and Survival Equipment, Mark 1, Mod 0 (EASE) and the British Mark VII Submarine Escape Immersion Suit (SEIS)

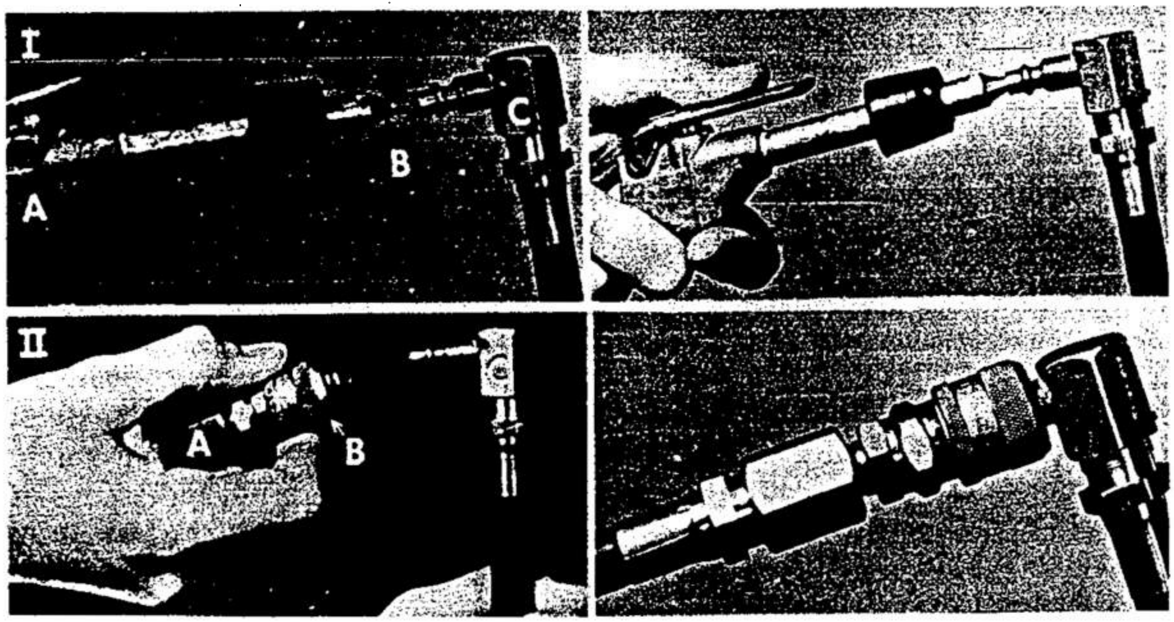

Fig. 4. I. The Type I connector. Tip (B) of gun-type charging device (A) is inserted into the male Schrader connector for charging.
II. The Schrader connector. Collar (B) of the female Schrader connector (A) is pulled back to allow joining with the male Schrader connector.

a male component, attached to the escape appliance, and a female component, attached to the air supply line. The connector locks together and the escapee pulls back a collar on the female component to break the connection when charging is complete. The Type I connector (Figure 4-I) is a simulated quick disconnect device. The female Schrader component is replaced by a connector with a lever operated valve to control air flow, and a tapered tip for insertion into the small orifice of the male component of the Schrader connector. After inserting the tip into the male Schrader, the escapee charges his appliance by depressing the lever and breaks the connection by releasing the components. A rubber stopper placed over the tube of the Type I connector serves as an adaptor for use with the larger orifice of the male component of the HIS on the SEIS. A more detailed description of this application is given by Walters and Ryack. [6]

Although disconnect time can potentially be an important factor in escape time, there have been no evaluations of disconnect time under operational conditions. Ryack, Rodensky, and Walters[1], Ryack and Walters[2], and Ryack, Walters and Rodensky[3] did not include disconnect time in their measures of escape time. A second purpose of the present study; therefore, was to obtain measures of disconnect time under simulated escape conditions with both the standard Schrader connector and the Type I connector.

METHOD

Subjects

The subjects (Ss) were seven United States Navy Escape Training Instructors from the Submarine Escape Training Department of the Naval Submarine School, Naval Submarine Base New London, Groton, Connecticut. All Ss were highly trained and experienced divers. Four of the divers had served as Ss in previous studies and were experienced in the use of both the Steinke Hood and the SEIS. The remaining divers were experienced in the use of the Steinke Hood but had not used the SEIS. All divers were trained in the use of the EASE prior to the study and were thoroughly familiar with the similarities and differences between the Steinke Hood, the SEIS, and the EASE. This sample represents the whole population of Navy divers familiar with the EASE but does not represent the general population of Navy divers or submarine crews. The instructors were randomly formed into two teams of three Ss each. Because of other duties, one of the new Ss was unable to participate in the escapes from the side egress configuration and was replaced by a diver with equivalent experience.

Apparatus

The Naval Submarine Medical Research Laboratory Escape Trunk Simulator (ETS) was utilized in the configurations found to be the most difficult to escape from (side egress) and the easiest to escape from (top egress).[3] The major features of these configurations are shown in Figure 5. The rational and details relating to the selection of specific dimensions and components of each trunk configuration are discussed in Ryack, Rodensky, and Walters[1] and Ryack and Walters[2].

The basic configuration of the simulator is that of a tube egress escape trunk. The side egress escape trunk configuration was composed of a cylindrical insert which reduced the internal dimensions of the ETS, a side hatch, and decking. The hatch of the side egress trunk lies below deck level, that barrier to escape was simulated by mounting a rectangular frame, constructed of tubing, above the hatch (Figure 5A). For top egress, simulator diameter was reduced by an insert, a top hatch was provided, and a 20-inch skirt was extended into the trunk from the hatch. Internal hardware was reproduced by means of mock-ups of tubing, controls, gauges, knobs, etc. The side egress hatch was friction loaded so that a force of approximately 20 pounds was required to open it. Since the hatch of the top egress trunk is to open with equalization of trunk and bottom pressure, it was mounted in an open position.

The ETS was submerged in 11 feet of water in a pool at the New London Laboratory, Navy Underwater Systems Center. Monitoring of the escape procedure and data recording was accomplished by means of closed circuit television. An operations monitor activated by a keyboard provided a record of the time in seconds and the time sequence for each subject. A signal light served as a 10-second warning signal for the subjects. The offset of the signal light was synchronized with the onset of the

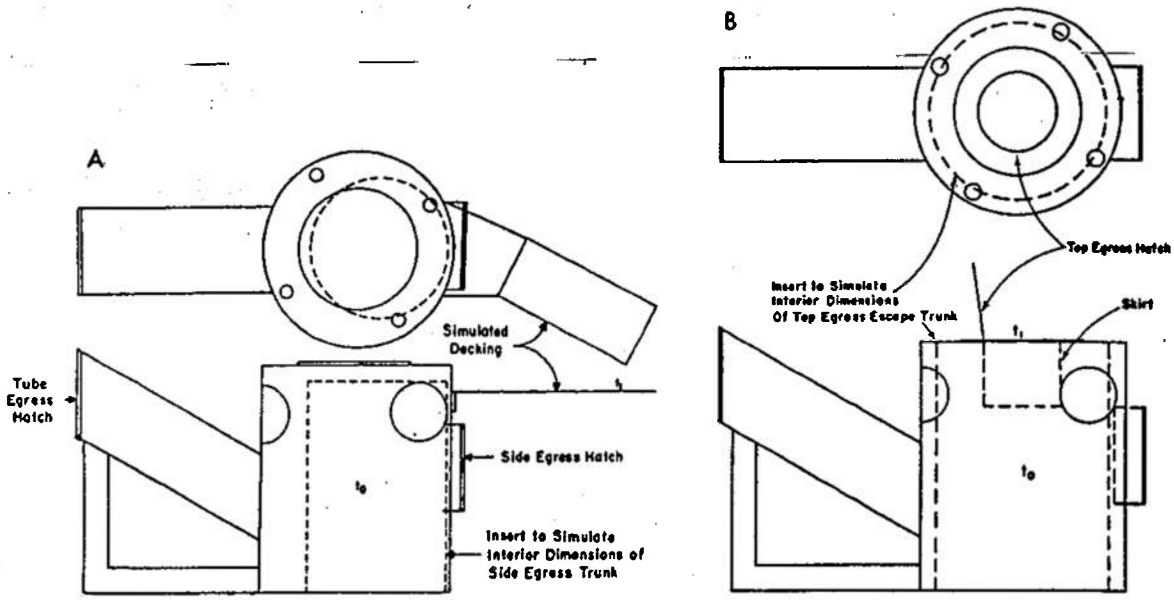

Fig. 5. Diagram of the Naval Submarine Medical Research Laboratory Escape Trunk Simulator (ETS) showing its configuration for side egress (A) and top egress (B). Interior details have been omitted. <u>*t*</u> *indicates data collection point.*

timing circuit. A more detailed description of the data recording and timing system is given in Ryack, Rodensky, and Walters[1] and Ryack and Walters[2].

Supply lines within the ETS, fitted with either the standard Schrader connector or the Type I connector, were used to supply external compressed air for charging the hood and stole portions of the EASE. Contact between the <u>S</u>s in the trunk and the surface was maintained by means of a Y Square Model 10-220 Yack/Yack Underwater communications system.

Design and Procedure

A four factor experimental design was employed. The factors were disconnect system, escape trunk configuration, team size, and subjects. Within each team, <u>S</u>s made two one-man escapes, four two-man escapes, and six three-man escapes in a random sequence with each combination of trunk configuration and disconnect system. The order of running the two disconnect systems was counterbalanced as was the pairing of <u>S</u>s for two-man escapes and the order of egress of <u>S</u>s for two-man and three-man escapes. All <u>S</u>s escaped from the top egress trunk configuration first.

<u>S</u>s inflated their appliance immediately upon entering the trunk. At the offset of the signal light (t_0) the <u>S</u>s began escape. For a side egress, the first man to escape broke the charging connection, pushed open the hatch and

left the trunk. He then passed through the simulated decking to the surface. As the first man left the escape trunk, the next man (in a two-man or three-man escape) began his egress. With the top egress configuration, the first man to escape positioned himself under the skirt. At the offset of the signal light he broke the charging connection and began escape. The remaining escapees followed.

RESULTS

The measure of escape efficiency was taken as the time from the offset of the ready signal (t_0) to the completion of escape (t_1). For the side egress simulation, t_1 was defined as the time at which the escapee's chest cleared the decking; for the top egress simulation, it was taken as the time at which the chest cleared the hatch (Figure 5). The data appears in the Appendix, Table 1.

Mean Total escape time for escape trunk configuration, disconnect system, and team size is summarized in Table 1. Differences between the means were tested with a four factor repeated measurements analysis of variance (Table 2). The main effects for team size and for escape trunk configuration, and the team size linear trend were all significant at less than the .001 level. None of the other main effects nor any of the interactions were significant. Significantly shorter egress times were obtained for the top egress trunk configuration than for the side egress configuration. There was a significant linear increase in egress time as team size increased.

To assess the effects of team size, escape trunk configuration, and disconnect system for a given egress position within an escape team additional analyses of variance were performed. The mean time for the first man to egress was evaluated across all three team sizes (Table 3). A similar analysis was made across two- and three-man teams for the second man (Table 3). Differences between trunk configuration were significant ($p < .001$) for both the first man and the second man to excape. A significant effect for disconnect system ($p < .05$) was obtained for the first position. There were no other significant main or interaction effects. Egress time for the first and second man to escape was not effected by team size. For both escape positions egress time was more rapid for the top egress trunk configuration than for the side egress configuration. For the first man to escape egress time was significantly more rapid with the Type I connector than with the standard Schrader connector. This difference was not significant for the second man. Since there were no teams with more than three men, it was not possible to evaluate the third position.

Discussion

The primary purpose of the present investigation was to evaluate escape capabilities with the EASE as compared to that with the SEIS. Two earlier studies on side egress[1] and top egress[2] were used as the basis for this evaluation. Since these studies utilized only the Type I connector, the present data for the Schrader connector was not included in the evaluation. The subjects

Table 1. Means and Standard Deviations of Escape Time by Team Size, Position, and Escape Trunk Configuration for the Type I and Schrader Connectors*

Team Size	Escape Trunk	Connector	Position 1		Position 2		Position 3	
			$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
1	Side	Type I	9.47	1.47				
		Schrader	10.05	1.64				
	Top	Type I	1.73	0.33				
		Schrader	2.17	0.90				
2	Side	Type I	8.85	1.37	14.03	2.56		
		Schrader	9.63	1.37	13.76	1.38		
	Top	Type I	1.68	0.23	4.47	0.98		
		Schrader	2.17	0.64	5.17	1.34		
3	Side	Type I	8.49	1.00	13.35	2.16	17.93	3.41
		Schrader	9.84	2.24	13.37	1.95	17.83	2.50
	Top	Type I	1.83	0.28	4.56	1.08	8.00	1.39
		Schrader	2.37	1.31	5.04	1.77	8.35	2.52

*All escape times are in seconds.

Table 2. Analysis of Variance for Team Size, Disconnect System, and Escape Trunk Configuration

Source	df	MS	F
Team Size (T)	2	308.76	112.20**
Linear	1	617.41	224.35**
Quadratic	1	0.12	0.43
Disconnect System (D)	1	1.42	0.40
Escape Trunk (E)	1	1415.12	240.63**
Subjects (S)	5	0.92	
T X D	2	0.24	0.17
T X E	2	5.59	1.94
D X E	1	0.82	0.45
T X S	10	2.75	
D X S	5	3.50	
E X S	5	5.88	
T X D X E	2	0.47	0.60
T X D X S	10	1.43	
T X E X S	10	2.88	
D X E X S	5	1.82	
T X D X E X S	10	0.79	

** Significant at beyond .01 level.

Table 3. Analysis of Variance for Team Position During Escape

Source	FIRST MAN			SECOND MAN		
	df	MS	F	df	MS	F
Team Size (T)	2	0.50	0.55	1	0.92	0.56
Disconnect System (D)	1	8.68	6.83*	1	0.64	0.37
Escape Trunk (E)	1	984.94	181.37**	1	933.24	242.81**
Subjects (S)	5	0.92		5	2.74	
T X D	2	0.31	0.42	1	0.01	0.01
T X E	2	0.87	2.14	1	0.81	0.94
D X E	1	0.78	0.95	1	1.56	1.55
T X S	10	0.91		5	1.63	
D X S	5	1.27		5	1.74	
E X S	5	5.43		5	3.84	
T X D X E	2	0.18	0.53	1	0.19	0.27
T X D X S	10	0.74		5	0.56	
T X E X S	10	0.41		5	0.86	
D X E X S	5	0.82		5	1.01	
T X D X E X S	10	0.34		5	0.72	

** Significant at Beyond .01 level
* Significant at Beyond .05 level

for all three studies were drawn from the same population of experienced divers and the data, which is summarized in Figure 6, was collected under similar experimental conditions.

There was no difference in top egress escape times between the SEIS and the EASE. However, with a side egress configuration escape time was somewhat more rapid for the EASE. The SEIS data for the side egress configuration was taken from the first study in this series.[1] Subsequent to this study the data recording system was modified to provide for more accurate data collection. The difference between the SEIS data and the EASE data is probably attributable to this change.

Table 4 summarizes the maximum possible depth from which safe no-decompression ascents can be made from each escape trunk configuration. The corrected total bottom times, which represent the 99th percentile, were derived by adjusting the obtained mean egress time for its variance ($\bar{x}$ + 2.33σ) and adding an assumed compression time of 20 seconds.[4,7,8] The corrected values may be expected to be exceeded in only one percent of the escapes. Egress capability remains fairly constant for the two escape appliances. The results support the findings of our previous studies,[1,2,3] top egress provides much shorter escape times and therefore shorter bottom times than side egress and one-man escapes provide a greater margin of safety than do three-man escapes.

Although more rapid egress times were obtained with a Type I connector

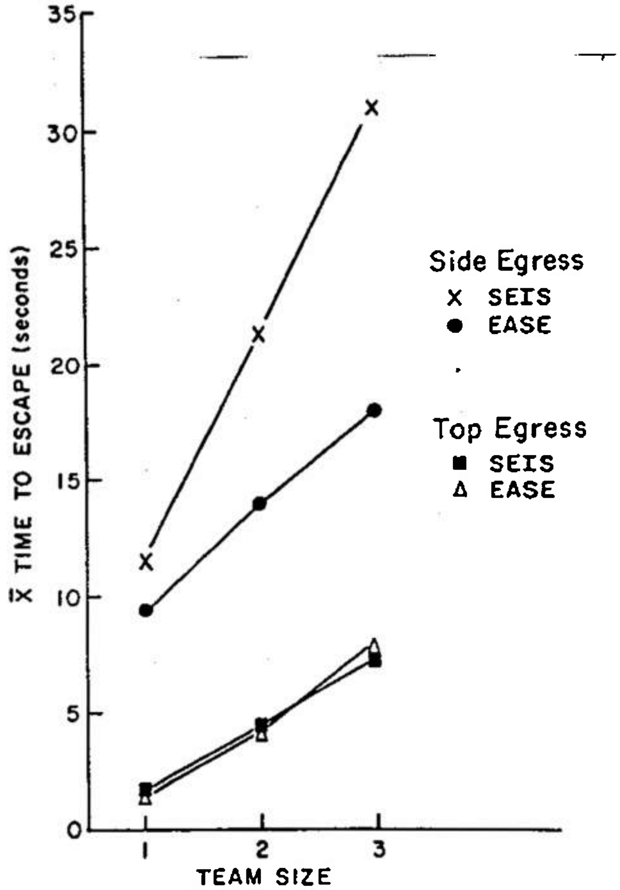

Fig. 6. Relative side and top egress times for the SEIS and the EASE.

than with the Schrader connector the differences between the mean escape times for these two configurations was not significant. Analysis of the data by position of the escapee, however, resulted in significantly shorter egress time in the first position for the Type I connector. Disconnect system was an important variable for the first man to escape but not for the subsequent escapees. This difference is attributable to the fact that the second and third man to escape begin their disconnect while the first man is making his egress. The absolute magnitude of this difference in egress time isrelatively small

Table 4. Maximum Possible Ascent Depths Based Upon Egress Time and No Decompression Time Limits

Trunk Type	Escape Appliance	Team Size	Mean Egress Time (Seconds)	Total Bottom Time Corrected for Variance and Compression Time (Seconds)	No-Decompression Time Limits (Seconds)	Maximum No-Decompression Ascent Depth (Feet)
Top Egress	SEIS	1	1.75	22.54	30	600
		2	4.57	26.38	30	600
		3	7.39	29.51	30	600
	EASE	1	1.73	22.50	30	600
		2	4.47	26.75	30	600
		3	8.00	31.24	45	500
Side Egress	SEIS	1	11.63	42.14	45	500
		2	21.31	54.45	60	450
		3	30.91	64.80	75	400
	EASE	1	9.47	32.90	45	500
		2	14.03	39.99	45	500
		3	17.93	45.88	60	450

(0.44 sec.) but it represents 25.4 percent of the total egress time.

An additional reason for evaluating the configuration of the disconnect system relates to the effect of the stress of an escape situation upon the ability of the subject to release the connector. Although our studies have been carried out under relatively nonstressful conditions, there were several instances during which the subject was unable to release the connector. Under the stressful conditions of an actual escape the number of such instances might be expected to increase. Support for this point of view is to be found in the experience of the British in training non-experienced divers.* During the conditions of actual escape the non-experienced diver does not readily break the connection between his air supply and

**Personal communication from CDR Mathew Todd, British Royal Navy, Retired.*

his suit. With the British system the buoyancy of the suit automatically or breaks the friction connection when the escapee is lifted from the escape trunk and this is not a major problem. With the Schrader type of connector the inability of the escapee to break this connection because of stress could result in avoidable loss of life. Additional evaluations of the Schrader disconnect system and alternate disconnect systems are required.

Recommendations

The newly developed Escape and Survival Equipment, Mark 1, Mod 0, (EASE) may be substituted for either the current escape appliance, the Steinke Hood, or the escape appliance developed by the British, the SEIS, with no loss in escape capability. Since the EASE provides greater exposure protection than the Steinke Hood, its adoption by the United States Navy is recommended.

To make the EASE compatible with existing escape trunk hardware, the standard Schrader disconnect system is utilized. This system is potentially hazardous because an escapee may be unable to effect a disconnect. Development of a new disconnect system to provide for increased safety in escape is recommended.

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Table 1. Raw Data: Table of Obtained Egress Times

Group	One Man Escapes		Two Man Escapes			Three Man Escapes			
	Cell	t_1-t_0	Cell	t_1-t_0 First Man	t_1-t_0 Second Man	Cell	t_1-t_0 First Man	t_1-t_0 Second Man	t_1-t_0 Third Man
Standard Schrader Connector - Top Egress									
1	B	1.7	b-A	1.6	3.2	ab-C	1.9	4.0	5.8
	B	1.3	c-B	1.4	3.7	bc-A	1.7	3.5	6.9
	C	1.3	b-C	2.9	5.8	ac-B	1.8	3.2	5.4
	A	1.8	c-A	2.0	3.6	ca-B	1.6	3.1	7.1
	C	1.6	a-C	2.0	3.9	ba-C	1.8	3.5	5.8
	A	2.1	a-B	1.8	6.0	cb-A	1.6	3.8	6.7
2	B	2.8	c-B	1.9	4.8	cb-A	6.1	8.4	11.5
	C	4.1	b-C	2.7	6.2	bc-A	1.9	5.6	8.3
	C	3.7	a-C	1.7	5.2	ba-C	2.4	5.4	9.2
	B	2.0	b-A	3.6	7.6	ab-C	2.3	6.1	9.5
	A	1.7	c-A	2.6	6.2	ac-B	1.7	7.0	13.3
	A	1.9	a-B	1.8	5.8	ca-B	3.7	6.9	10.7
Type I Connector - Top Egress									
1	B	1.7	b-A	1.8	4.6	ab-C	1.7	4.2	6.3
	B	1.8	c-A	1.3	4.1	ca-B	1.6	3.8	9.3
	C	1.1	b-C	1.7	3.3	cb-A	1.6	3.5	7.1
	A	1.3	c-B	1.3	3.6	ac-B	1.4	3.3	5.5
	C	1.7	a-B	1.5	4.0	ba-C	1.7	3.5	7.0
	A	1.3	a-C	1.5	3.3	bc-A	2.0	4.7	7.8
2	B	2.0	b-A	1.8	4.1	ab-C	1.6	4.6	10.1
	A	1.8	a-B	1.8	4.4	ba-C	1.9	4.1	8.1
	C	2.0	a-C	1.8	4.8	ac-B	1.9	4.6	7.7
	A	2.0	c-A	1.9	6.7	cb-A	2.0	6.8	9.3
	C	2.0	b-C	1.9	5.4	bc-A	2.3	5.9	8.3
	B	2.1	c-B	1.9	5.3	ca-B	2.3	5.7	9.5

Table 1. (Cont.)

Standard Schrader Connector - Side Egress										
Group	One Man Escapes		Two Man Escapes			Three Man Escapes				
	Cell	t_1-t_0	Cell	t_1-t_0 First Man	t_1-t_0 Second Man	Cell	t_1-t_0 First Man	t_1-t_0 Second Man	t_1-t_0 Third Man
1	C	10.9	a-B	9.1	14.2	bc-A	12.4	14.8	20.7
	A	12.2	c-A	10.1	12.9	cb-A	10.8	15.4	18.6
	B	10.2	b-A	10.0	13.8	ab-C	8.2	10.9	17.5
	C	10.1	c-B	10.9	15.5	ca-B	11.6	13.0	15.3
	A	9.7	a-C	8.9	13.6	ba-C	7.7	10.1	15.2
	B	8.6	b-C	9.6	14.2	ac-B	7.2	11.2	14.4
2	A	12.9	c-A	8.9	11.9	ca-B	8.6	14.0	19.0
	C	8.0	a-B	11.4	16.1	cb-A	13.4	16.8	20.9
	B	9.1	a-C	9.8	14.6	ba-C	7.9	13.2	18.0
	C	7.9	c-B	7.5	11.4	ac-B	9.6	13.4	17.0
	A	11.9	b-C	7.5	12.6	bc-A	7.9	13.0	15.4
	B	9.1	b-A	11.9	14.3	ab-C	12.8	14.6	22.0
Type I Connector - Side Egress									
1	C	11.3	b-C	11.0	18.5	ba-C	7.4	10.1	15.1
	B	9.4	a-C	8.6	15.1	ab-C	7.9	13.1	18.2
	B	9.3	c-B	10.7	18.5	bc-A	9.0	16.6	20.5
	A	10.7	b-A	9.9	14.7	ca-B	10.0	14.5	26.0
	A	8.2	a-B	9.5	13.8	ac-B	8.8	12.1	16.8
	C	11.8	c-A	9.9	11.1	cb-A	9.3	13.6	16.3
2	A	9.1	b-C	7.6	15.0	cb-A	6.7	10.9	13.9
	A	11.0	b-A	9.2	12.6	ab-C	9.5	12.8	17.8
	C	8.2	c-A	7.2	10.6	bc-A	9.2	15.6	17.2
	B	9.0	a-C	7.5	12.5	ca-B	7.3	10.9	14.4
	C	6.8	c-B	7.2	14.2	ac-B	8.3	13.5	17.3
	B	8.9	a-B	7.9	11.8	ba-C	8.5	16.5	21.7